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by

M. Ye. Drits, Z. A. Sviderskaya, N. Ye. Nikitina

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NEW MAGNESIUM ALLOYS FOR OPERATION AT ELEVATED TEMPERATURES

M. Ye. Drits, Z. A. Sviderskaya,
and N. Ye. Nikitina

The requirement in contemporary technology for light and high-strength structural materials has lent special urgency to studies directed toward increasing the mechanical properties of alloys based on magnesium, which has a low specific weight (1.8-1.9 g/cm^3). It is a known fact that the addition of rare and rare-earth metal to magnesium alloys makes it possible to increase the properties of these alloys at both room and elevated temperatures. Deformable alloys on a magnesium base alloyed with cerium, neodymium, zirconium, lanthanum, and thorium have been developed and have found application [1-4]. Indications have appeared in the literature in recent years on using refractory metals as alloying elements in magnesium alloys; these include yttrium and scandium, which are similar to rare-earth metals in physicochemical properties [5-8]. Factors which indicate promise in using these metals as alloying elements with magnesium include their comparatively low specific gravity (4.5 g/cm^3 for yttrium and 3.0 g/cm^3 for scandium) and the favorable physicochemical interaction of yttrium and scandium with magnesium. Yttrium forms a eutectic with magnesium, but one

with a sufficiently high nonvariant transformation point (565°) [9, 10], while scandium interacts with magnesium by a peritectic reaction at 705° [11, 12]. Both elements form a wide region of solid solutions with magnesium, with the solubility of yttrium in solid magnesium changing significantly with temperature. Studies carried out at the A. A. Baykov Institute of Metallurgy, AS USSR, to determine the effect of yttrium and scandium on the structure and properties of magnesium and certain magnesium alloys made it possible to develop new heat-resistant deformable magnesium alloys based on the system Mg-Sc-Y-Mn [13-15].

Study of the mechanical properties of quaternary Mg-Sc-Y-Mn alloys in the hot-extruded state at room and elevated temperatures showed that alloys in this system, with adequate ductility, possess high strength characteristics at both room and elevated temperatures. Figures 1 and 2 show curves of ultimate strength and yield point as a function of test temperature for two alloys containing scandium and yttrium (Mg, 11% Sc, 7% Y, 0.6% Mn - curve 1 and Mg, 11% Y, 6% Sc, 0.6% Mn - curve 2) and also curves for existing heat-resistant deformable magnesium alloys MA11 (curve 3), MA12 (curve 4), and VMD1 (curve 5); the properties of alloys MA11 and MA12 are given in state T6, and those of alloy VMD1 in the hot-extruded state. From the curves it is clear that the strength properties of the Mg-SC-Y-Mn alloys are substantially superior to those of alloys MA11 and MA12, alloyed with neodymium, and also higher than those of alloy VMD1, containing thorium, in the temperature range 20-300°.

Thus, the ultimate strength of alloys containing scandium and yttrium is 6-12 kgf/mm^2 higher than that of the alloys MA11, MA12, and VMD1 at room temperature: at 250° the advantage is 9-19 kgf/mm^2, while at 300° it is 8-16 kgf/mm^2. A similar superiority is noted in yield strength. At temperatures of 350-400° ultimate strength and yield points of Mg-Sc-Y-Mn alloys

are somewhat higher (2-8 kgf/mm^2) than the similar characteristics for alloys MA11 and MA12 and they are close to those of alloy VMD1.

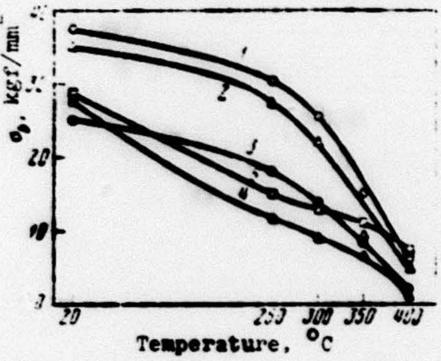

Fig. 1.

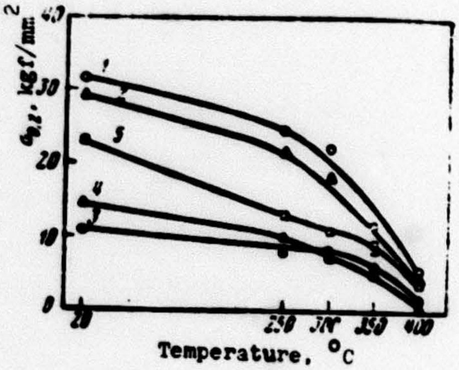

Fig. 2.

Fig. 1. Ultimate strength of Mg-Sc-Y-Mn alloys and the alloys MA11, MA12, and VMD1 as a function of test temperature.

Fig. 2. Yield point of Mg-Sc-Y-Mn alloys and the alloys MA11, MA12, and VMD1 as a function of test temperature.

The compressive yield strength of alloys containing scandium and yttrium (determined at room temperature) is only 1-2 kgf/mm^2 less than the yield point under tension, while the other deformable magnesium alloys are characterized by a substantial superiority of yield strength under tension as compared with compressive yield strength. Magnesium alloys containing lithium are an exception in this respect [16, 17].

The mechanical properties of the new alloys in the rolled state can be seen from the data in Table 1.

Thus, in the extruded and rolled states the mechanical properties of magnesium alloys from the system Mg-Sc-Y-Mn at room temperature fall on the level of the most high-strength contemporary deformable magnesium alloys. At the same time

Table 1. Properties of Mg-Sc-Y-Mn alloys in the hot-rolled state (thickness 2 mm).

Composition of alloys	20°			250°			300°		
	σ_b, кГ/мм²	$\sigma_{0.2}$, кГ/мм²	δ, %	σ_b, кГ/мм²	$\sigma_{0.2}$, кГ/мм²	δ, %	σ_b, кГ/мм²	$\sigma_{0.2}$, кГ/мм²	δ, %
Mg — 11% Sc — 7% Y — — 0,6% Mn	34,0	26,0	9,0	29.5	22,0	16,0	23,0	17,5	27,0
Mg — 11% Y — 6% Sc — — 0,6% Mn	33,0	25,0	10,0	29,0	22,0	15,0	26,0	20,0	28,0

Designation: кГ/мм² = kgf/mm².

at 250-300° the strength properties of these alloys are somewhat higher than those of all existing heat-resistant magnesium alloys.

Figure 3 shows microstructures of Mg-Sc-Y-Mn alloys in the cast and hot-extruded states. The structure of the extruded alloys is partially recrystallized. In addition to grains of solid solution enriched with magnesium, excess phases are observed in the structure: crystals of manganese, the intermetallic compound $Mg_{24}Y_5$, and dark crystals of a ternary compound in the alloy which is richer in scandium. After pressure working the base states are found in the form of chains along the direction of deformation. The microstructure of the alloy enriched with scandium is more uniform as compared with the alloy rich in yttrium.

The high strength properties of Mg-Sc-Y-Mn alloys at room and elevated temperatures apparently stem from the presence in the base of these alloys of a strongly alloyed quaternary solid solution, and also from heterogenization of the structure by dispersed particles of refractory intermetallic compounds [18-20]. The retention of high strength properties by the alloys at elevated temperatures is connected with the favorable physicochemical interaction of scandium and yttrium with

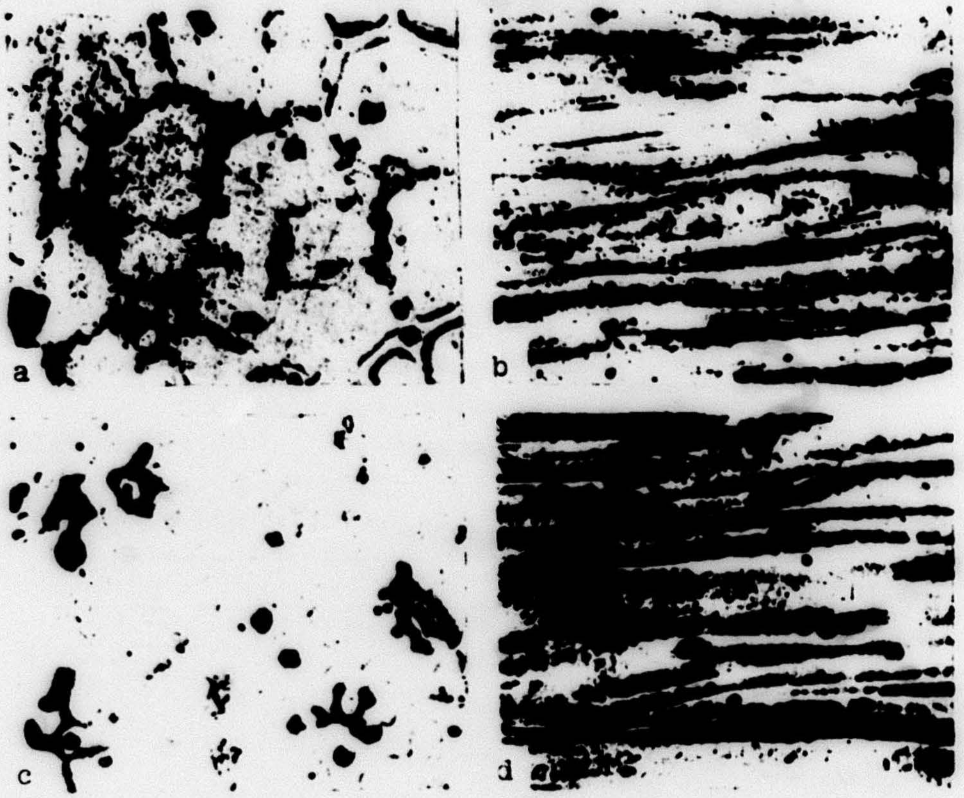

Fig. 3. Microstructures of the alloys Mg + 11% Y + 6% Sc + 0.6% Mn (a, b) and Mg + 11% Sc + 7% Y + 0.6% Mn (c, d) in the cast (a, c) and hot-extruded (b, d) states (magnification 440).

magnesium and with one another, the presence of a broad region of solid solutions, an adequately high solidus temperature of the alloys and a high recrystallization temperature, low diffusion mobility of the components, and low rates of recrystallization and coagulation processes of the separating dispersed particles of intermetallic phases.

The effect of heat treatment on the mechanical properties of Mg-Sc-Y-Mn alloys can be seen from Table 2, which presents the properties of these alloys in the hot-extruded state and after heat treatment (aging, 200°-100 h).

The data in the table indicate that heat treatment led to an increase in strength properties for the alloy Mg + 11% Y + 6% Sc + 0.6% Mn by 3-5 kgf/mm^2 at both room temperature and at 300°. Heat treatment had virtually no influence on the strength properties of the alloy enriched with scandium. Relative elongation and impact toughness of the Mg-Sc-Y-Mn alloys were somewhat lower after heat treatment. Thus, the alloy enriched with yttrium possesses higher strength properties in the heat-treated state, while the alloy enriched with scandium has higher properties in the hot-extruded state.

Table 2. Mechanical properties of Mg-Sc-Y-Mn alloys in the hot-extruded and heat-treated states.

Alloy composition	State of alloy	20°				300°		
		σ_b, кГ/мм^2	$\sigma_{0.2}$, кГ/мм^2	δ, %	$a_н$, кГм/см^2	σ_b, кГ/мм^2	$\sigma_{0.2}$, кГ/мм^2	δ, %
Mg — 11% Sc — 7% Y — 0.6% Mn	Hot-extruded	37,5	31,5	9.5	0,87	25.5	21,7	34.5
	Heat treated	36,2	31.0	8,0	0,62	26,0	22.0	28.0
Mg — 11% Y — 6% Sc — 0,6% Mn	Hot-extruded	35.0	29,0	7,0	0.37	22,0	18,0	48.0
	Heat treated	38.0	33.5	5,0	0,24	27,0	23,0	29.0

Designation: кГ/мм^2 = kgf/mm^2.

Table 3 shows specific weights and values of ultimate strength for Mg-Sc-Y-Mn alloys and for the alloys MA11, MA12, and VMD1 at room and elevated temperatures. The data in this table indicate that despite the somewhat greater specific weight as compared with alloys containing neodymium and thorium, the materials alloyed with scandium and yttrium are substantially superior in ultimate strength in the temperature interval 20-300°. At 350° the ultimate strength of alloy VMD1 exceeds that of the alloy Mg + 11% Y + 6% Sc + 0.6% Mn, and at 400° is greater than that of the alloy Mg + 11% Sc + 7% Y + 0.6% Mn, but this superiority is not great.

Table 3. Ultimate strength of Mg-Sc-Y-Mn alloys as compared with alloys MA11, MA12, and VMD1.

Alloy composition	State of the alloy	Specific weight γ, g/cm^3	Ultimate strength σ_b/γ				
			20°	250°	300°	350°	400°
Mg — 11% Sc — 7% Y — 0.6% Mn	Hot-extruded	1.91	19.6	16.1	13.4	7.1	3.2
Mg — 11% Y — 6% Sc — 0.6% Mn	Hot-extruded	1.92	18.2	14.2	12.0	4.7	2.5
Mg — 2.7% Nd — 2% Mn — 0.2% Ni (MA11)	T5		20.0	—	14.1	—	2.2
	T6	1.80	14.0	10.0	7.6	4.8	1.1
Mg — 3.8% Nd — 0.42% Zr (MA12)	T6	1.80	15.8	8.8	4.9	3.6	0.8
Mg — (2.5—3.5) % Th — (1.2—2.0) % Mn (VMD1)	Hot-extruded	1.81	15.4	8.2	7.1	6.0	3.9

The stress-rupture strength for the alloys with scandium and yttrium is higher at 250° than for existing heat-resistant deformable magnesium alloys. Thus, for the alloy Mg + 11% Sc + 7% Y + 0.6% Mn, $\sigma_{100}^{250°}$ = 12.0 kgf/mm^2 in the hot-extruded state, while for the alloy MG + 11% Y + 6% Sc + 0.6% Mn it is 14 kgf/mm^2 in the heat-treated state; the values of this property for the alloys MA11 and VMD1 are 9.0 and 11 kgf/mm^2, respectively (data are given in state T6 for the alloy MA11 and in the hot-extruded state for alloy VMD1).

Considering that alloy VMD1 has not found practical use in our country owing to the toxicity of the radioactive thorium in it, alloys of the system Mg-Sc-Y-Mn can apparently find use as semiproducts for structures operating at temperatures at of 250-400°. The combination of a high level of strength properties at room and fairly high temperatures and the possibility of obtaining extruded and rolled semiproducts from these alloys are favorable properties which distinguished them from existing standard and experimental deformable magnesium alloys.

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